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SENSORY PERCEPTION OF SURFACE QUALITY
INDUSTRIAL PRACTICES AND PROSPECTS

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ABSTRACT

In this paper we carry out a critical analysis of the industrial practices used by the partner firms to control a product's appearance. The group of partners represents many different sectors of activity such as: luxury goods industry, furniture industry, medical equipment (prosthesis), plastic injection and watch-making industry. These practices deal with the identification of appearance anomalies, the evaluation of an anomaly's severity as well as the decisions about the product's conformity. We will show that current practices do not allow us to decrease the variability of the results frequently observed, because the subjectivity often associated with this kind of control is not eliminated using such methods. In every sector studied, we find the same dissatisfaction about the results obtained.

We will then present our approach to sharply decrease this variability. This approach, tested in a famous Swiss watch-making company, is based on sensory analysis concepts. This approach is original due to the breakdown of the visual-control process into three sub-processes: the detection of appearance anomalies, the evaluation of those anomalies and the decision about conformity. This approach also includes a metrological organization and some tools which allow us to measure the efficiency reached. The paper will show how our approach succeeds in meeting the different aims of the partner company group and proposes an initial structured approach for a generic metrological organization adapted to the control of the variability during surface quality control by humans.

Keywords: *quality, visual appearance control.*

1. INTRODUCTION

Product quality is usually defined as "the characteristics which allow the implicit and expressed needs to be satisfied" [1]. So, the level of product quality strongly depends on its functional skills, its reliability, and its cost or even on the quality of the associated services (after-sales, guarantee…). However, the quality also depends on the way the customer perceives the product [2]. This perceived quality, which is evaluated by visual, tactile, acoustic, gustatory and olfactory impressions [3], plays a very important role in order to reach the best quality of a product proposing more than functional efficient products but also esthetic efficient products. At the same time, Forslund [4] shows the effect of geometric variation on perceived quality. The visual robustness of geometrical variations is so presented as a side of perceived quality.

Our work deals with one criterion of the perceived quality: the appearance of a product's surface. This study is part of a European research program « INTERREG » bringing together two laboratories from the two universities, university of Savoy and the Lausanne federal polytechnic school (EPFL), two institutional partners: CTDEC and CETEHOR and six industrial firms. The aim of this project is to create methodological support and the tools needed to improve the visual control of high added value products.

First of all, in this paper we carry out a critical analysis of the industrial practices used by the partner firms to control product appearance. The group of partners represents many different sectors of activity such as: the luxury goods industry, the furniture industry, medical equipment (prosthesis), plastic injection and the watch-making industry. We will then present the tools we propose to provide solutions to the problems.

2. INDUSTRIAL PROBLEMS

This diversity shows the universality of the perceived quality problematic. However the objectives of appearance control differ depending on the product specificities and its market positioning. Indeed, for the luxury goods industry and furniture industry the way to reach a quasi perfect esthetic imposes its own criterion. For the plastic products, the appearance control allows us to show out the deviance of the fabrication process in order to guarantee the product's functionalities. In the medical field (prosthesis fabrication for example) the appearance of the product gives an idea to the consumer of the global quality level of the product (resistance, functionality, reliability). Therefore appearance control presents specifics problems. Despite this diversity, all the partner firms meet behind the same problem: how to build a sensory evaluation process which is repeatable, reproducible and stable over time.

The subjectivity of human judgment in terms of esthetics and perception introduces variance in the control results. The problem of repeatability and reproducibility is mainly due to this variability [5]. This variability can be explained by the variance of the measure conditions, of the semantics and cognitive process of perception between controllers [6, 7, 8] and the perception and judgment performances of one controller at a different time, due to his emotion or his tiredness [9].

More than punctual disagreement about the product's conformity, this omnipresent subjectivity induces difficulties to maintain a precise level of quality. Experience shows that controllers tend to be more and more strict there by increasing the minimum level of quality.

3. PRACTICES ASSESMENT

Due to the lack of recognized universal approaches, each firm sets up special practices in order to solve the visual appearance control problems. But in all firms, the management committees are not satisfied with the control efficiency and the controllers complain about how hard it is to respond to the task. Here is the list of the most frequent complaints:

Table 1: Complaints list

Too many defects are not detected No stable level quality over time	Very long learning period Different judgment depending on the controller
Unjustified rejects Decision-making problems	Communication difficulties in the supply chain One unique person as a referent

We noticed that all the complaints come from the repeatability and reproducibility problem:

The Repeatability is defined as the ability of the appraiser to "repeat" his/her decisions (agree with him / herself). Calculated as (# agreements / # parts inspected)

And the Reproducibility: Ability of all the appraisers as a whole to "repeat" their decisions among them. Calculated as (# agreements among all appraisers / # parts inspected)

The reproducibility result is made up of three components: Concordance: (# parts that agree with the standard / # parts inspected).

False Alarms: (# parts classified as "defective" when in fact there are perfect / # of perfect parts)

Wrong Classification: (# parts classified as "perfect" when in fact there are defective / # of defective parts)

In this paper we want to make a list of the most significant practices we come across in the different firms. Then we propose an analysis of theirs relevance and efficiency. This repeatability and reproducibility problem is one of the most important points. In this paper we also want to highlight the origins of this problem.

3.1. A rich and varied vocabulary

To harmonize judgments, the use of a common and shared vocabulary is very important. However, we noticed that the controllers in the partner firms use too many terms to describe the different kinds of anomalies (from a few dozen to one hundred fifty terms). Moreover, the terms used, often mix the nature, the causes or even the consequences of the anomaly. Table 2 groups a few examples of terms or expressions used in the firms:

Table 2: Examples of descriptions used in companies

Deformation, blur, stripe, bubble, sandpaper traces	Run out welding, scraping, sanding, laser tackles	Appearance, brightness, engraving, defects, painting drop

The lack of clarity concerning description of the anomaly is, once again, a source of variability in anomaly judgment. [10, 11]

The sensory analysis method named "free choice profiling" does not impose any constraints concerning the terms to be used: "descriptors" [12]. Those methods are easier to set up but provide a more personal judgment (no common criterion) and are subjective (no references) without any justification.

In the case of visual appearance control, we tried to evaluate and organize the sensory perceptions to give a shared judgment compares to common criterion (even if they are not the controller's criterion). That is why using the conventional profiling method (finite number of descriptors) allows us to reduce the variability in judgment, making the anomaly description and categorization task easier and insuring a good communication between controllers. But the efficiency of this method comes from the right choice of descriptors respecting some conditions of pertinence, independence, exhaustiveness and discrimination [13].

One important objective of this study is to evaluate the possibility of building a generic descriptor list which could correspond to all fields, to be used by all our industrial partners. In her work with a well-known Swiss watch maker, A.S.Guerra proposed a short-list of four descriptors respecting the previously named characteristics [5].

3.2. Use of anomaly panoply

As an answer to the stability of the level of quality, and judgment reproducibility, the firms had to keep in memory all the anomalies detected and the associated conformity judgments. This wish led the firms to build a whole database named "panoply". Those databases illustrate each anomaly with a picture or a real product having this anomaly. The main advantage of this tool is the knowledge capitalization of all anomalies within a firm depending on processes and products. This allows one to set up easily training programs easily, or make them a lot more efficient and to compare the nature of anomalies encountered from one firm to another depending on their sector of activity.

The panoplies sometimes gather hundreds of illustrations (pictures or products). An anomaly could have different impacts according to its physical position on the product, so several pictures may be necessary to define the level of conformity.

Panoplies represent the reference of the expected level of quality and is often used as a comparison tool to evaluate the quality of the product. Indeed, in some firms the panoplies are present at the work station, thus allowing the controllers to compare, treat and provide an opinion on conformity. But it is very difficult to compare anomalies with different intensities (deeper, longer, larger…), observed on different products (color, shape, material…). Thinking of building exhaustive panoplies illustrating all the level of intensity of all anomalies on every kind of product is just amazing because the panoplies are product oriented whereas they should be an illustration of the firm's level of quality. But even the firms don't have such a standard, it has to be defined, created and shared.

3.3. Evaluation criterion and decision process

In addition to the anomaly detection problems, evaluation and decision steps could be a source of variability and conflict. Every firm has different ways of taking care of this point.

The firms from the luxury industry are more sensitive and experienced in visual control than others, such as the furniture industry firms, for example. The size of luxury product anomalies makes the comparison of visual-impact harder and it becomes hard to judge the conformity of the product. So, in this kind of industry, panoplies are used as a comparison-evaluation tool which does not allow formalizing the criterion based on visual perception. This method is available because of the experience of the controllers and the sensitivity concerning the visual quality of the products.

In the more industrial firms, with less qualified employees, more automated machines and a faster rhythm of production, the evaluation can not be based on people's experience. Those employees from the "hyper-industrial" firms are generally less sensitive and trained to product quality and visual control. The conditions increase the difficulties of anomaly evaluation. The binary criterion "I see / I don't see" shortcuts the evaluation task. The decision thus depends directly on the control conditions (light orientation, detection distance, time…). By using this criterion, controlling the environment becomes mandatory.

3.4. Visual control process formalization

In order to transmit the visual-control instructions, the firms created the "control-procedures" which often gather the dimensional and appearances specifications of the product. Here we deal with the part of those "control-procedures" specifying the visual-appearance-control.

In practical terms this is a paper document specifying the firm's requirement and gives guidelines to the controller by listing the different kind of anomaly. The tolerance is often specified by giving the allowed number of unacceptable anomalies on the product. These documents also give the control frequency and the maximum number of defective products in case of batch control. The accuracy and relevance of those documents can vary a lot from one firm to another.

As evaluation criteria, the control-procedure mentions the different kinds of anomalies to detect, through the descriptors given. On the other hand, no anomaly quantification systems are set up, and we mainly noticed two different decision-making processes:

The worst case: no rules are defined and the controller, depending on his own perception, is in charge to judge the visual impact of the anomaly and provide an acceptance decision, by referring to the products in the panoply

The second significant practice we noticed is to define a simple rule concerning the visual impact of the anomaly. This rule is named "I see / I do not see". The principle is to define all the conditions of the control and remove the evaluation step. By respecting the observing conditions, if I see an anomaly, it is considered as a defect and the product is classified as unacceptable. In one of the partners, the control conditions are based on the physical conditions (location, orientation, illumination, distance…). This approach tries to bring the controller closer to the customer perception, but the diversity of such conditions makes the judgment not representative of the visual impact of a anomaly by the customer himself.

By analyzing the control-procedures used in every firm, we noticed that they always define "what" to control whereas they should define "how" to control by specifying a standard on the evaluation criterion and describing and imposing the environment conditions of the control. Mastering the detection process will allow one to guarantee the exhaustiveness of the control and permit to ensure the access to the necessary information for the evaluation or decision step.

A detailed analysis of the Ishikawa diagram applied to visual-control allows us to highlight the most influential factors on visual control. We could also separate the factors into two categories: influencing the detection step or the evaluation step. Even if several factors are easy to control, a lot depends on the product, the material, the process or even on the firm's organisation. The following table gathers some of the most influential factors:

Table 3: Most influential factors from an Ishikawa diagram

Material	Color / size, product shape / product position in final assembly / completion, texture (shiny, dull, rough, wet, soft…)
Manpower	Vision accuracy / controller's mental and physical state / instruction and anomaly interpretation / knowledge of the product
Means	Product handling
Method	Knowledge of the manufacturing process / production rate / additional task
Conditions	Illumination (intensity, orientation and dazzling) / work station ergonomics / noise / comfort of work /

Finally, we noticed that control-procedures mix three different concepts of visual-control: anomaly detection, anomaly evaluation and acceptance decision. The decision rule previously mentioned "I see/I don't see" translates this confusion between the three appraisals. Guerra [5] shows how necessary it is to separate these three appraisals [5], we will detail this point in the next part of this paper.

3.5. Tool aided detection

As we have just said, visual control contains in three distinct steps: detection – evaluation – decision. The evaluation step is often absent in the visual-control process and the detection and decision steps are unclear. The anomaly detection problem is often identified by the firms and they thus set up some tools to help their controllers. The two main factors identified are the size of the anomaly and the light used during the control.

Enlargement tool

The norm concerning the watch making industry [14] specifies controlling the products with normal vision (without enlargement tools). In spite of this norm, several firms propose or impose the use binocular to improve a controller's detection skills. In some cases, these tools can be useful or even necessary.

Some products may have very small dimensions and a lot of details. For example, the case of plastic injection products with very small holes: a diameter of less than one millimeter. That makes the control harder and extremely tiring for the eyes.

The second case concerns the size of the anomaly compared to the size of the product. For example, in the luxury industry, the product tends to perfection. This search for perfection induces the detection of the smallest anomaly (even if it is acceptable). The enlargement tools allows the detection of every anomaly, and thus to set up a performing evaluation step.

The light

Once again the norm [14] gives some recommendations about the lighting at the work station. A particular action is to use an 800 lux lighting source. However, this norm contains no specifications about more important points such as the position and the orientation of the light source(s).

Experience shows that defining the light intensity is not enough to ensure good detection. To decrease the variability of the control and make sure the work conditions are comfortable, specifying the intensity, position and orientation of the light is mandatory. Guerra [5] shows the impact of light orientation on anomaly detection and perception. The wrong practices within the firms are due to the lack of communication about this information.

3.6. Practices conclusion

The most important points:

Every firm developed its own tools depending on its own problematic

No specification of the visual control task, and conditions

Confusion between the three concepts: detection, evaluation, decision (in every firm)

Many subjective tools: panoply

The work with partner firms shows the variability of the practices to satisfy the visual-control. This variability is due to the product produced, which imposes very different manufacturing processes, production organization and different levels on esthetic and appearance property specifications. Thus the lack of recommendations, references and exchanges on this subject, each firm acquired its own experience. That explains the variability between the partner firms.

Within a firm the variability can be explained by product diversity, especially: size, color and shape. But it is mainly due to the freedom granted to controllers. This freedom in the task comes from the lack of definition, specification, formalisation and recommendation about visual-control. Thus every controller proceed by his own way, which could be different from one day to another depending on the mood, the place, the time of day, the motivation, the attention. Once again, this is the reproducibility problem. The impossibility of setting up a reproducible control comes from the difficulty in sharing the same criteria of evaluation and control conditions [15].

4. A STRUCTURED APPROACH

Human subjectivity is the main source of variability in the visual control task. The food industry has to set up sensory tests thanks to the sensory analysis method. Even if the industrial problematic and application fields are different, these sensory analysis methods allow the reduction of the variability in product evaluation unsing human senses (mainly taste and smell but also sight and touch). So the idea is to use sensory analysis tools, adapted to the partners' fields and products.

4.1. Sensory analysis : application to manufactured product

In the food industry, sensory analysis is used to classify products depending on a well-defined criterion to emit a personal judgment often independent of the experimentation's conditions. The different methods proposed in literature [12, 16] highlight the different kind of classification scale and present the most efficient comparison processes. One example of the food industry problematic: a study consists in classifying biscuit depending on the perceived sugar rate [16]. In this kind of study, it is known that the test morphology: scale used (free or structured) and the product-presentation-order influences the results. Yet this kind of influence is harmful in the case of industrial manufactured products.

A good aspect of the sensory analysis method as it is applied in food industry is the metrological structure. This structure is composed of experts who define the evaluation criteria, the acceptance limits, and they set up the references and the control morphology (as previously described). This structure is useful in setting up the experimentation objectives and deducing the conditions (time, tools, light) permitting to access to the mandatory information for the evaluation. Moreover, training, calibration and accompaniment are necessary to make sure the controllers use the tools correctly.

4.2. Split the concepts : detection, evaluation and decision

A previous study [5] carried out in a luxury watch allowing companies to evaluate the sensory analysis tool's relevance applied in the context of manufacture products. This study highlights the interest of separating the three concepts of visual control: anomaly detection, evaluation of perceived anomaly (work on descriptors) and final acceptance decision.

A good control comes from a good vision

To detect correctly, it is necessary to know « what » to see. It is proved that visual attention allows the concentration level and the performances of visual detection (in particular the contrast perception) to increase [17]. That is why it is important to identify the possible anomalies we want to detect on the product. Of course, these possible anomalies depend on the product, the manufacturing process… (even within a firm). Defining the characteristics and properties of the anomalies is necessary to use the right tools and method to be able to detect. To share this definition of anomalies, it is necessary to use common vocabulary.

The definition and identification of anomalies is the first step. The next step is the control-process standardization by procedures specifying:

- Ø Necessary skills (vision accuracy, color detection, common vocabulary…)
- Ø Tools to be used (light…)
- Ø Product, body and eye movements

This standardization helps the controller to be exhaustive during the detection task and allows access to information permitting the evaluation task. It also allows reducing practice variability during the detection.

A good evaluation comes from quantification and discrimination

The evaluation step consists in quantifying the visual impact of the detected anomalies. This visual impact is not measurable so the quantification is not easy. However it is possible to know the discriminating properties thanks to anomaly definition. For example a small stripe (small geometrical dimensions) on a black part will have a worst visual impact than a big stripe on a white piece. So the geometrical properties are not discriminating. Finding those properties is part of the whole project.

The quantification is an important step to associate a magnitude level to the visual impact of each anomaly. Panoplies are often used as a quantification scale. However part of the method is to give a common meaning to some word to be able to set this quantification without references. Finding factual evaluation criteria is one important objective of the project. Those criteria could be based on anomaly visibility properties: i.e. which conditions are necessary for me to perceive the anomaly?

The work on detection helping tools allows one to see more details and more anomalies faster than before. But more anomalies do not mean more defects. We thus noticed the importance of the evaluation step which allows us to make the difference between anomalies (acceptable) and defects (non acceptable).

A good decision takes into account all the parameters

The decision step is the last one, and gives the final answer concerning the product conformity. The anomaly localization is essential to determine its criticity. The decision, as in the dimensional metrology, depends on tolerances fixed by the expert group (often integrating the marketing decisions). The same gap between the reference surface and the real surface does not have the same visual impact depending on its location. Actually the localization analysis allows us to evaluate the risk for the customer to see the anomaly. Thus, the most visible zones are considered as the most critical.

Finally the decision step consists on putting together the results from each step:

- Ø Detection: which anomaly
- Ø Evaluation: which visual impact
- Ø Localization: where the anomaly is situated on the part

So, the decision is an objective judgment about the conformity based on subjective data from the previous steps.

Finally, some concepts used in the food industry are suitable to be used to control manufactured products. The difference between emitting a personal judgment (sensory analysis) and an objective evaluation based on defined criteria imposes an evolution of the evaluation tools. So the tools should allow more than a comparison, an evaluation based on common references, criterions and acceptance limits fixed by the expert group.

5. GENERAL CONCLUSION

In this study we noticed that due to the lack of specification, recommendation or even referent studies about visual control, each firm developed its own practices and tools. We noticed a great variability of those practices. So we noticed two different variability sources: the internal variability, the people's practices variations within a firm and the extern variation which defines the practices variability between several firms.

The first answer to this study is to reduce the internal variability by the definition of the control environment and the second one is to set up a generic method suitable for every field and firm. So, in several firms we are setting up a new kind of control procedures, specifying the control task. Those procedures take into account the fabrication process and the risk to create one anomaly in particular to specify what to detect. In addition to make the control easier and more efficient, most of the new procedures impose a visible defect detection course and the amount of time for the task. To control and reduce the environment variability, we are working on the lighting conditions. Several light sources configurations are studied to find the best conditions independent of natural light sources.

The approach needs the creation of the metrological structure. It is composed of a representative anomaly panel, an expert group emitting the "right" judgement and a training course regarding the evaluation of a measurement tool (the controllers). In every firm this group of expert has been created, and a panoply illustrating the most significant defects has been created. The next step is to create a tool illustrating the decisions taken by the expert group. To set up this tool we need to know the criteria of each expert and make them agree about the "generic criterion" to be understood and shared by everyone.

Finally, one of the most important points is to split the control along the three visual control concepts. The detection step imposes a control of the observation conditions, to evaluate then correctly, a definition of shared evaluation criterion is mandatory and the definition of acceptance limits and critical zones in the product will allow us to make the right decision automatically.

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